3.0 Operational ES&H Practices

This section of the report focuses on the work activities and hazards encountered by workers at the Plant from 1952 through 1990. While not exhaustive, it is intended to provide specific information on the majority of the activities and chemical and radiological hazards encountered during normal operations and maintenance. It is structured in two parts. Section 3.1 discusses the general hazards, including industrial, chemical, and radiological hazards, present at the Plant and the programs in place to address those hazards. Section 3.2 discusses the specific activities performed by workers, emphasizing the specific hazards encountered during the course of those activities, and controls implemented to reduce the hazards to workers. Appendix B summarizes the principal hazardous activities, the controls used to mitigate the hazards, and their effectiveness.

In general, it was apparent from interviews and records that the AEC, its successor agencies, and the operating contractors understood the unique hazards associated with operating a gaseous diffusion plant. They identified a variety of controls, such as respirators, special clothing, and procedural requirements, to address those hazards. However, primarily due to the classified nature of much of the work, workers were not always made fully aware of the extent of those hazards. The contractors, from the outset, did not normally provide exposure data to workers unless specifically requested, nor did they inform workers that exposure data was available upon request. Consequently, workers believed they were not receiving any appreciable exposure. This led to a belief among workers that the identified controls were not really necessary. Foremen and supervisors did not emphasize the need for these controls, leading to an undisciplined application of controls such as self-monitoring, use of respirators, and showering before leaving the Plant.

Exposure to radiological and chemical hazards was more likely in certain areas of the Plant. Feed production operations in C-410 and C-420, neptunium and technetium recovery operations in C-410, cleaning operations in C-400, tails reduction to green salt and uranium metal in C-340, filter bag replacement, and repairs and modifications of compressors and converters were some of the more hazardous tasks. Records showed that high airborne concentrations of radioactive materials in these areas were common, and evidence suggests that worker exposure monitoring may not have been adequate in these areas. Full-time hourly employees (e.g., security, groundskeeping, and maintenance) performing tasks in a variety of buildings were considered transient workers and were generally not afforded the same level of protection as individuals dedicated to specific Plant areas whose exposures were more predictable. As a result, contamination protection may not have been adequate, and Plant-wide dose statistics may have been underreported.

Finally, although recent worker concerns have focused on radiological hazards, the chemical hazards faced by workers on a daily basis were significant. In certain areas, HF was probably continuously present. The number of workers recorded as reporting regularly to the medical facility for HF burns reflects this hazard. Even more workers were exposed on a regular basis to HF than reported to the medical facility.

3.1 Hazards and Controls

3.1.1 Hazards

- *Radiological Hazards*
- *Chemical Hazards*
- *Industrial Hazards*

The PGDP operations exposed workers to a wide variety of radiological, chemical, and industrial hazards. Some of these hazards and their health effects were known from the early years of the Plant's history. For example, most physical hazards, such as working on scaffolding and vehicle safety, were recognized early in the Plant's history and addressed through procedures, safety bulletins, safety committees, and JHAs. Many of the radiological hazards were also identified in the early years of the Plant. However, the health effects and hazard controls were often not effectively communicated to workers by line management, nor did line management or workers adequately implement the hazard controls. Some chemical hazards and their health effects, such as fluorides, carbon tetrachloride, and TCE, were recognized early in the Plant's history. However, the hazards of some substances in use at the Plant since startup, such as PCBs and asbestos, were not recognized until the 1970s, as was the case nationwide. This section summarizes the principal radiological, chemical, and industrial hazards to which workers at PGDP were exposed between 1952 and 1990.

Radiological Hazards

- *Uranium*
- *Uranium Daughters*
- *Transuranic Elements*
- *Fission Products*

Since the early 1950s it was known that the operation and maintenance of gaseous diffusion plants, metals production facilities, and auxiliary units involved processing large quantities of radioactive materials. Such materials included uranium, concentrations of uranium decay products, and concentrations of transuranics and fission products. From 1957 into the mid-1960s, numerous studies were performed on the radiological effects of neptunium, plutonium, technetium, and other fission products and transuranic elements on workers. The studies found low concentrations of impurities in the incoming reactor tails. However, these impurities tended to concentrate in certain areas and processes of the feed plant and the cascade. Twenty-five percent of the incoming neptunium was deposited in the ash, filters, and dust of the feed plant. Fifty percent remained in the cylinder heel or on the cylinder walls, and the remaining 25 percent was vaporized to the cascade and plated out primarily in the upper stages of the cascade. Ninety-nine percent of the plutonium was deposited in the ashes, filters, and dust of the feed plant. Approximately 0.9 percent remained in the cylinder heel or on the cylinder walls, and the remaining 0.1 percent was vaporized to the cascade and plated out primarily in the first stage of the cascade it encountered.

The policy in place at PGDP to protect personnel from the hazards inherent in the handling of radioactive materials from the outset was based on preventing personnel exposures from exceeding the Radiation Protection Guides (RPGs) established by the Federal Radiation Council, the provisions of AEC manual chapters (subsequently, ERDA and DOE orders), or those established by the National Committee on Radiation Protection and Measurement (NCRP). The AEC policies in place at the time further encouraged the maintenance of radiation doses as far below applicable standards as was practical. The appropriateness and application of these policies from 1952 to 1990, and the expectations that employees would adhere to guidelines, were key factors in how well PGDP identified and controlled hazards.

Uranium. Uranium is an element that naturally occurs in the earth and is mined for commercial purposes. Natural uranium is 99.3 percent uranium-238 and 0.7 percent uranium-235; uranium-235 is used as nuclear reactor fuel. Enriched uranium contains more uranium-235, and depleted uranium contains less U-235, than natural uranium. U-238 has a radioactive half-life (the period of time for material to decay to half of its initial radioactivity) of 4.47 billion years. Once in the body, uranium may concentrate in the kidneys and bones or lungs, depending on its solubility. As a heavy metal, uranium is toxic and can damage the kidney. At enrichments less than 10 percent (PGDP's maximum enrichment is less than 5 percent), for soluble compounds, uranium's chemical toxicity to the kidney predominates over its radiological hazards. For insoluble forms, radiation dose to the lung can be the predominant concern. The principal sources of internal uranium exposures at PGDP relate to the inhalation or ingestion of both soluble and insoluble compounds. During enrichment, UF_6 was used as a gas for processing, as a liquid for feeding and withdrawing, and as a solid for storing and transporting. When released as a gas, UF_6 hydrolyzes with moist air to produce HF (which can cause chemical burns and is an eye and respiratory irritant) and UO_2F_2. Additionally, other compounds of uranium, such as UF_4 and UO_3, were present in significant quantities in many PGDP processes.

Uranium Daughters. The beta radiation dose rate at the surface of uranium metal is typically 230 millirems per hour or less. However, when uranium is melted or separated by chemical or physical means, less-dense daughter products of uranium, primarily thorium-234 and protactinium-234m, can be concentrated. When the uranium is further processed, significant quantities of these daughter products can remain behind in the form of oxides or ash or on the surface of process vessels. Locations of daughter products at PGDP include: the feed plant fluorination towers (primarily from ash receivers and the sintered metal filter baths), in C-400 and C-720 from converter disassembly work, in C-400 at the cylinder wash facility, in C-310 and C-315 in cylinder heels (feed and withdrawal), in C-340 from shell and crucible cleaning, and in C-400 and C-710 in the neptunium and uranium recovery process raffinate. The beta radiation dose rate from these residual daughter products is much higher than that of the original uranium. In addition, these daughter products are loose and easily transferred by contact. Exposure to these daughter products as a result of transfer to clothing, tools, or other items is likely to result in unanticipated beta radiation doses to workers. Protactinium-234m emits a high-energy beta particle, which contributes most of the beta dose from the uranium-238 daughter products.

Transuranic Elements. Transuranic elements have atomic numbers greater than 92 (i.e., greater than uranium). They can be produced when U-238 absorbs neutrons as part of a nuclear reaction. Among the transuranic elements are neptunium and plutonium. Transuranics were introduced to PGDP when feed material from processed spent reactor fuel was received from the Hanford and Savannah River sites.

- Neptunium-237 – Neptunium-237 has a radioactive half-life of 2.14 million years and is far more hazardous than natural uranium. The specific radioactivity of neptunium-237 (7.01×10^{-4} Ci/g) is 2,000 times higher than the radioactivity of depleted uranium. Neptunium, at the low concentrations found in reactor tails feed material (about 0.1 gram of neptunium per ton of UO_3), was not a significant radiological hazard. At such levels, the controls applied to protect against uranium exposure provided ample protection from neptunium. However, neptunium tended to concentrate at certain points in the uranium conversion, enrichment, and recovery processes. The highest concentrations of neptunium were associated with neptunium recovery processes that operated intermittently at Paducah from 1958 until the late 1970s, in C-400 and C-710. Neptunium recovery was a classified program, and neptunium was referred to by the code name "Trace."

  Although neptunium had been present in PGDP feed materials since 1953, it was not detected at the Plant until 1957. The detection of neptunium was significant to the Paducah health physics staff. They knew that traditional uranium controls would not be sufficient for areas where neptunium would concentrate because of the quantity present combined with neptunium's relatively high specific radioactivity and radio-toxicity. The personnel exposure pathway of principal concern was the inhalation of particulate material contaminated with neptunium. Analysis of radiation dose due to inhalation required knowledge of particle size and solubility. A 1959 solubility analysis by ORNL found a sample of PGDP dust contaminated with neptunium to be insoluble in blood serum. A 1961 analysis of particle size determined the mass median particle size to be three microns. A value of 10 dpm/m^3 was selected as the airborne concentration of neptunium considered safe for continuous occupational exposure. This value was appropriate in that it was about the same as the MPC specified for soluble neptunium-237 by the 1959 edition of National Bureau of Standards (NBS) Handbook 69, and was only about five percent of the Handbook MPC for insoluble neptunium-237.

  In mid-1959, neptunium contamination was first discovered on a piece of cascade equipment. That year, four Plant personnel who worked with neptunium-237 solutions were sent to the In Vivo Radiation Monitoring Laboratory (IVRML). The whole body counts were negative. A 1960 memorandum between AEC, OR, and PGDP describes discussions with an AEC representative who visited the site and provides insights into neptunium exposure problems at PGDP. The memorandum notes a significant exposure potential to neptunium and states that there were "possibly 300 people at Paducah who should be checked out but they hesitate to proceed to intensive studies because of the union's use of this as an excuse for hazard pay." In 1962, 14 workers from various Plant locations, including those who were believed to have the greatest potential exposure to neptunium-237 and uranium, were sent to the IVRML. Whole body counts did not reveal neptunium-237 body burdens as significant as one-half the allowable body burden, and the urinalyses were inconclusive.

  Air in neptunium processing areas was continuously sampled and analyzed for radioactivity on a monthly basis. The sample results reviewed by the investigation team revealed that airborne radioactivity in neptunium processing areas was, at times, higher than the maximum permissible concentration for neptunium. For example, reports of continuous sampling for the months of February and March 1959 indicated an average of 10 and 27 dpm/m^3 respectively in the neptunium recovery area in C-710. Judging by today's dose models, workers exposed in these areas during these two months could have received significant radiation doses. The doses would not have been significant if the source has been uranium. Little is known about respirator use during maintenance and operation of the neptunium recovery system. Interviews with several workers assigned to other areas where neptunium hazards existed, and documented findings in these areas by the AEC, indicate that respirators were not consistently worn when they were needed. Further, a health physics inspection report documented that respirators were not worn during dismantling of the neptunium recovery system in 1974.

- Plutonium-239 – Plutonium is significantly more radioactive than neptunium, but constituted a lesser hazard at PGDP because it was present in much lower concentrations. Recent estimates indicate that only 328 grams of plutonium were present in approximately 89,000 metric tons of uranium fed into the PDGP cascade. Plutonium concentrated in the UF_6 feed production facility. Because it remained with the ash material, most was removed with the ash residues and particulate filter in the conversion of UF_4 to UF_6. Individuals who could have been exposed to plutonium at PGDP are most likely those who were exposed to dust while changing the particulate filter and emptying the ash collector. Other possible exposures to plutonium could have occurred in the feed cylinder wash area, the uranium recovery system raffinate, and the filter wash and reside waste packaging area. Workers in the cascades, product withdrawal, or tails withdrawal areas were essentially not exposed to plutonium.

  Plutonium-239 has a radioactive half-life of 24,065 years. The specific activity of plutonium is 6.22×10^{-2} Ci/g. Of particular importance for radiological safety considerations are the solubility, particle size, and surface area of plutonium compounds. These properties play an important part in the transportability of plutonium in the environment and in the body. Currently, all plutonium compounds, except the oxides, are assumed to be mostly soluble in the lung; the oxides are assumed to be mostly insoluble. Unfortunately, few data on particle size are available, and those that have been generated focus on the reactivity of the materials in the separation and conversion processes. Much of the data is reported as crystallite size, which relates to surface area and solubility but not necessarily to the way the particles would be dispersed in the air. Factors affecting plutonium's biological effects include its mode of entry into the body and its distribution in the body. Once plutonium reaches the bloodstream, it accumulates primarily in the liver and skeleton. Plutonium exposure may produce acute health effects (e.g., inhalation may lead to pulmonary edema, and ingestion may lead to damage to the walls of the gastrointestinal tract) or long-term effects, such as increased risk of cancer. Ingestion of about 0.5 gram of plutonium would be necessary to deliver an acutely lethal dose. The literature indicates that inhalation of about 20 milligrams of plutonium dust of optimal size would be necessary to cause death within roughly a month from pulmonary fibrosis or pulmonary edema. Inhalation of less than acutely lethal quantities of plutonium increases the probability of cancer. When plutonium is inhaled, the lungs are exposed to alpha-particle radiation, increasing the risk of lung cancer, and the plutonium is eventually carried to other organs, where the radiation can cause cell damage and increase the likelihood of biological effects.

Fission Products. Fission products are elements created when uranium-235 is split by neutrons as part of a nuclear reaction. They typically have atomic mass numbers in the range of 80 to 108 and 125 to 153. The predominant fission product at PGDP was technetium.

Technetium-99 has a radioactive half-life of 213,000 years and was received at PGDP in recycled feed from the Hanford and Savannah River Sites. Technetium passed through the PGDP cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the enriched uranium product. The AEC did not specify a limit for technetium in UF_6 feed but controlled the concentration of technetium indirectly to about 10 ppm by limiting gross beta due to fission products. Technetium is a weak beta emitter (0.29 MeV); the primary exposure pathways are dose to the skin due to skin contamination or internally due to ingestion or inhalation. Although technetium was not a significant radiological hazard during most PGDP operation and maintenance activities, it presented a more significant hazard when concentrated in recovery processes in C-400.

Chemical Hazards

- *Fluorine*
- *Trichloroethene*

- *Chlorodiphenyl*
- *Fungicides*

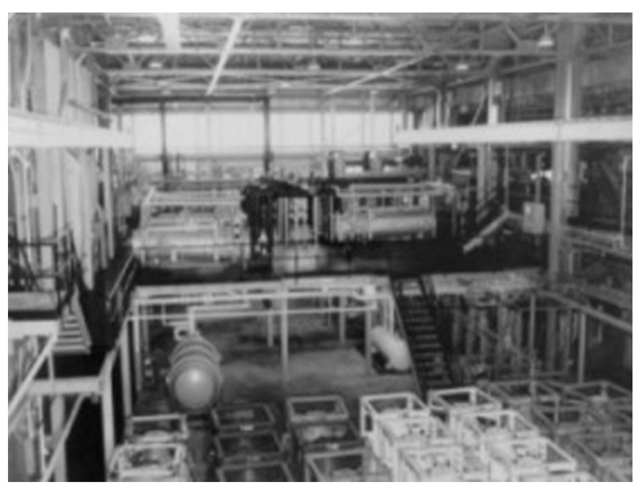
Many chemical hazards, other than fluorides, were not recognized nationwide until the early 1980s for two fundamental reasons. First, the hazards and health effects of some chemicals (e.g., PCBs) were not well known. In the 1960s, for example, there was limited knowledge about the hazards of many Plant chemicals, with a few exceptions such as fluorides, carbon tetrachloride, and TCE. More important, there were few regulations requiring that workers be informed of chemical hazards in the workplace. The issuance of the OSHA Hazard Communication Standard in the early 1980s was the single most important regulation affecting chemical hazard identification at the Paducah Plant. The Hazard Communication Standard required the identification of chemical hazards in the workplace, labeling of chemicals with their health hazards, documenting a chemical hazard program, training workers, and most importantly requiring manufacturers to develop and disseminate Material Safety Data Sheets to chemical purchasers. The implementation of the Hazard Communication Standard (procedure development, worker training, chemical inventorying, and labeling) was the most significant activity for the Paducah Industrial Hygiene Department during the early 1980s.

Although the Hazard Communication Standard was of significant importance in establishing chemical hazard identification and worker protection programs, there had been chemical standards, requirements, and some knowledge of the hazards of chemicals at the Paducah Plant since the early 1950s. For example, Plant Concentration Guides for some chemicals were evident in the 1950s. As early as 1956, industrial hygienists were evaluating the substitution of less-hazardous chemicals for a variety of work activities, such as substituting Samae (a cleaning solvent) for nitric acid, and TCE in lieu of carbon tetrachloride. In the 1960s, Paducah adopted the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for those chemicals that had established TLVs. The adverse health effects of carbon tetrachloride had been widely known since the 1920s. During the first quarter of 1960, industrial air sampling for chemicals was first documented in the Health Physics and Industrial Hygiene Quarterly Report. Chemicals reported were ammonia, hydrogen sulfide, mercury, nitrogen dioxide, phosgene, and TCE. Arsenic was present due to impurities in the feed material. Measured airborne chemical concentrations were compared to Maximum Airborne Concentration (MAC) Guides. Since 1960, however, the ACGIH TLVs for most of these chemicals have been lowered, some by as much as by a factor of 4 or more. As a result, some airborne chemical concentrations reported as acceptable in 1960 would be considered an overexposure by today's standards. For example, in 1960 a reported worker exposure to 60 ppm of TCE was well within the MAC Guide of 200 ppm. However, the TLV for TCE today is 50 ppm, and 60 ppm would be considered an overexposure. Similarly, in 1965, an exposure to TCE at concentrations of 150 ppm in C-600 was recorded as acceptable by comparison to the Plant Concentration Guide of 350 ppm.

Some offsite chemical hazards were identified as early as December 1957, when a program for monitoring gaseous fluorides at the Plant perimeter commenced. This program was an addition to the monitoring of fluorides in grass, which had begun some time earlier. Reporting of site boundary and offsite releases of fluorides continued through the 1960s and 1970s.

Fluorine. Fluorine is a pale-yellow to greenish gas with a pungent, irritating odor. Hydrogen fluoride or hydrofluoric acid (HF) is a colorless gas or fuming liquid with a strong, irritating odor. Exposure routes include inhalation, skin absorption (liquid), and skin and/or eye contact. Exposures can result in a variety of symptoms, ranging from irritation of mucous membranes to severe burns.

Fluorine and its compounds, such as HF, UF_4, and UF_6, were used throughout the Plant processes, particularly in C-340, C-410, C-420, and throughout the cascade process buildings. Fluorine and anhydrous HF were used in the fluorination of uranium dioxide. HF was a common byproduct when UF_6 was inadvertently released to work spaces and combined with moisture in the air. HF was also a byproduct of metal production.



Fluorine Plant

Fluoride hazards were identified early in the Plant's history. Most quarterly Health Physics and Hygiene reports from 1953 through 1972 routinely reported urine levels of uranium and fluorides in selected groups of workers. The third quarterly report for 1954 indicated that HF burns were a concern, but that long-term health effects were not known. After this period there is limited recorded evidence of worker exposures to fluorides until the 1980s, when there was a re-emergence of interest in HF exposures. During the first three decades of Plant operation, safety and health professionals were more concerned with uranium exposures than exposures to fluorides, since the latter were perceived as "repairable." For most of this period, fluoride levels, as measured in urine samples, remained constant at around 1 mg/L. Typically, one to four workers per quarter exceeded the Plant Concentration Guide of 4 mg/L and were placed on restricted duty. As late as 1971, overexposures to HF were being reported. Today, urine samples continue to provide a valuable indication of exposure to fluorides, but principally as a supplement to monitoring the air in a worker's breathing zone. During this period, exposure-monitoring practices shifted from monitoring workers after exposure to a contaminant to sampling air before or during exposures. The 4 mg/L Plant Concentration Guide adopted at Paducah (i.e., 1.3 mg/g to 8 mg/g creatinine) would appear to be conservative by comparison to today's standards. However, a number of variables (e.g., sampling frequency, exposure time, and analytical methods) make this comparison of marginal value.

Trichloroethene (TCE). TCE is a colorless liquid with a chloroform-like odor that is often used as an industrial degreaser. TCE is a mild irritant to the respiratory tract and the skin and is considered by some as a potential carcinogen, based on animal studies. Critical exposure pathways are inhalation, ingestion, and skin or eye contact. When humans are exposed, TCE concentrates in the respiratory system, heart, liver, kidneys, central nervous system, and skin.

During PGDP construction, all process piping was degreased presumably with TCE. Prior to startup of C-400, some of this work apparently occurred south and east of the Building C-333 and is suspected as being a TCE source of the Northeast plume. Since the commencement of operations, TCE was used throughout the Plant in varying quantities. The most significant use of TCE was in Building C-400, in which large components (valves and converter parts) were degreased in TCE vats, which were accessed through an overhead crane. Other components were cleaned and degreased in smaller vats of TCE in Building C-720. Significant amounts of TCE were used in the PGDP electrical switchyards. In addition, maintenance and operations workers routinely used smaller quantities of TCE throughout the Plant as a general-purpose cleaning agent. TCE releases to the surrounding area were evident throughout the history of the Plant, with elevated concentrations of TCE being recorded in outfalls as further discussed in Section 4.3. Investigating the contribution of TCE sources to groundwater contamination has been a major focus of the Administrative Consent Order and the Federal Facility Agreement.

Chlorodiphenyl or PCBs. PCBs are colorless to lightly colored, viscous liquids with a mild odor. They are generally used as a cooling medium in transformers and at PDGP in ventilation system gaskets as a fire retardant. The critical pathways of exposure are inhalation, ingestion, and absorption. When humans are exposed, PCBs concentrate in the skin, eyes, and liver.

During the mid-1970s, recognition of PCB hazards at PGDP emerged—about the same time as in commercial industries. OSHA also adopted 14 carcinogen standards that addressed PCBs as well as other hazardous materials. In 1975, preparations were under way for a two-year program to provide formal respiratory training on a sitewide basis. PCBs, which were in widespread use by the Plant throughout its early history, were not considered a hazard until the early 1980s. In 1980, the newly formed Waste Management Group performed the first Plant-wide PCB inventory in response to new TSCA regulations on PCBs. By 1982, a PCB program was in place to consider PCBs as an environmental contaminant and a regulated waste. However, there was little concern over worker exposure to PCBs through absorption, and many workers wore PCB-contaminated clothing. Some workers considered PCBs to be an effective remedy for dry skin.

Fungicides. Fungicides were occasionally used during the Plant's history as an organic material preservative. Fungicides (and pesticides) can enter the body through ingestion, inhalation, and absorption pathways, with skin absorption being a primary concern. Health effects can vary from minor headaches and nausea to debilitating conditions of the central nervous system.

Paducah's 14 cooling towers are protected from microbiological and chemical attack by a comprehensive program of water treatment, tower maintenance, and fungicide spraying. The towers are treated annually with fungicides, principally to protect wooden components from fungal attack and deterioration. In 1958, a variety of fungicide sprays containing zinc sulfate, arsenic acid, and potassium chromate were tested. In the early 1980s, a modified in-place fungicide treatment process was developed that was based on pentachlorophenol, a common wood preservative, fungicide, and algacide often used for treating cooling towers. The application of these fungicides usually requires PPE consisting of chemical suits and self-contained breathing apparatus and/or local ventilation. Pentachlorophenol, for example, is highly toxic and considered to be both a carcinogen and a possible teratogen (causes fetal malformations).

At PDGP, workers in air-supplied hoods and chemical suits performed fungicide-spraying operations, since the concentration of the fungicide in air often exceeded the regulatory value. Hazards and controls for the spraying operation were identified in JHAs. Air monitoring in the 1980s reportedly demonstrated that none of the spray team would inhale air containing fungicidal concentrations over the regulatory limits.

During team interviews, some former carpenters, having previously seen the fungicide spray team in their air-supplied neoprene suits, expressed concern that their carpentry work activities on and in the dry cooling towers could have resulted in an overexposure to fungicides. Carpentry work was performed without PPE. Although a JHA was developed in 1981 for cooling tower inspection, no hazard analysis was performed for carpentry work, nor was there a requirement for chemical protective clothing or air monitoring. Respirators were not required until the mid- to late 1980s. Although the carpenter's exposure to dust laden with fungicides may have been minimal, there was no evaluation of the residual effects of these fungicides and no basis for determining protective clothing requirements.

Industrial Hazards

- *Physical Hazards*
- *Dust, Noise, and Asbestos*
- *Beryllium*

Since the 1950s there has been a conscientious effort by line management to identify and quantify industrial worker hazards at the Paducah Plant, commensurate with the science and understanding of those hazards for that period in time. Retrospectively, this does not imply that with today's knowledge, today's health and safety professionals would perform the same activities or arrive at the same conclusions as the health and safety professionals in the 1950s concerning the identification and quantification of Plant hazards during that period. For example, asbestos has been a significant hazard at the Plant since construction. However, asbestos hazards were not recognized, and efforts to sample and quantify airborne levels of asbestos were not initiated at the Paducah Plant until the 1970s. An OSHA asbestos standard was published in 1971. Routine monitoring of asbestos did not occur until the 1980s. Similarly, some other industrial hazards (e.g., beryllium and PCBs) were not well recognized in industry during the early decades of the Plant's history. Throughout the decades, identification of a hazard often resulted in changes in PGDP facilities, processes, or procedures to reduce or eliminate the hazard.

Physical Hazards. Work activities at the Plant involved a wide variety of physical hazards, including electrical work, working at elevated heights, material handling, welding, vehicle operations, and machining of parts. The Paducah Plant Safety Department was issuing safety procedures, standards, bulletins, and manuals as early as mid-1953. These early publications focused on a variety of physical hazards and issues such as housekeeping, fall protection, floor markings, signs on safety showers, vehicle accidents, and fire protection.

Dust, Noise, and Asbestos. Some hazard identification activities at the Paducah Plant were state-of-the-art for their time. Quarterly Health Physics and Hygiene reports from the 1950s, for example, identify hazards associated with airborne chemical contaminants, dust, and noise. Research in establishing the efficiencies of new types of respirators was evident in the mid-1950s, although the practice of exposing human subjects to gaseous clouds of HF in order to quantify a respirator's efficiency would not be condoned today. During 1954 and 1955, dust hazards were investigated throughout the Plant. Equipment was borrowed from Oak Ridge to help quantify particle size distribution as an aid in selecting respiratory protection. During 1957, a Plant-wide noise exposure evaluation resulted in recommendations for hearing protection and noise-suppression modifications to the Plant. In 1967, a paper on the "Paducah Plant Hearing Conservation Program" was presented at the annual AEC conference.

Asbestos was not recognized as a hazard at Paducah until the 1970s or later. Asbestos had been widely used for construction, welding, and insulation since the early 1950s due to its resistance to heat, flames, and corrosive chemicals. Asbestos fibers are carried into the body as airborne particles, and these fibers can become embedded in the tissues of the lung and digestive system. Once the fibers become trapped in the lung's alveoli (air sacs), they cannot be removed. Years of exposure to asbestos causes a number of disabling and fatal diseases, including asbestosis, an emphysema–like condition; lung cancer; mesothelioma, a cancerous tumor that spreads rapidly in the cells of membranes covering the lungs and body organs; and gastrointestinal cancer, which is caused by ingesting asbestos-contaminated food. During the fourth quarter of 1973, some of the first air samples for asbestos were taken and sent to ORNL for analysis. The PGDP asbestos program began in 1986.

Beryllium. Beryllium is a silver-gray metallic element used as a pure metal, as beryllium-copper and other alloys, and as beryllium oxide. Beryllium is useful in weapons production due to its strength, light weight, relatively high melting point, and machinability. The severity of the health hazards that can result from even minimal contact with beryllium are only now beginning to be fully understood. Beryllium can enter the body through inhalation, skin absorption, skin wounds, and ingestion. The most serious health effects come from inhaling airborne insoluble particles that deposit in the lungs. Chronic beryllium disease, which occurs in one to six percent of exposed workers, has a latency period of up to 20 years and no known cure.

There is no clear evidence of beryllium machining at PGDP during this period. However, as part of the work for others program, machining or cleaning of beryllium-copper components may have been conducted in the 1960s; beryllium was one of the substances in industrial hygiene air samples during this period. For example, a 1968 internal memo indicated that a heat-treat furnace contaminated by beryllium at another AEC installation was cleaned in C-710 without personnel exposure. In general, there was no evidence of airborne beryllium or overexposures.

3.1.2 Programs and Controls

- *Hazard Identification and Analysis, and Safety Training Programs*
- *Hazard Communication Program*
- *External Exposure Monitoring Programs*
- *Bioassay – Urinalysis Programs*
- *Bioassay – In Vivo Radiation Monitoring*
- *Air Sampling*
- *Contamination Control*
- *Personal Protective Equipment*
- *Respiratory Protection*
- *Medical Programs*

Health and safety programs at PGDP were established at the commencement of Plant operations and continue to the present day. Health physics, industrial hygiene, and medical functions were integrated in the Health Physics and Hygiene Department for the first three decades of Plant history, and under the direction of the Plant Medical Director, this integrated several safety disciplines with a focus on worker health. From the commencement of operations until the Tiger Team evaluation in 1990, both health physics and industrial hygiene were minimally staffed, especially in comparison with the number of safety professionals that would be required today for the types of hazards and work activities present. The Health Physics Section from the commencement of operations until 1990 ranged in size from as few as two to six employees. The Industrial Hygiene Section typically consisted of one or two industrial hygienists and a technician. Furthermore, in the early decades, health and safety professionals had limited authority and resources to ensure that line management would implement recommended hazard controls. The primary responsibility for protecting personnel against hazards associated with radioactive materials was placed on line supervision to the same extent that they were responsible for operation and production.

During the first three decades, the Health Physics and Hygiene Department provided workers and line management with the following basic programs and services:

- Monitoring exposures to determine the effectiveness of the health physics program
- Auditing and maintaining records of exposures (radiological, noise, chemicals) and radiation data collected throughout the Plant
- Furnishing line supervisors with advice, information, and training aid on chemical, radiological, or uranium toxicity health hazards
- Assisting in investigations of personnel exposures
- Providing film badge services
- Maintaining the bioassay and respiratory protection program for both chemical and radiological exposures

- Performing chemical and radiological environmental monitoring for the Plant
- Recommending radiological and chemical Plant guidelines for controlling exposures
- Conducting air sampling for airborne chemicals and radioactive material.

C-400 Building

As early as the 1950s, PGDP set forth in policy and Plant procedures the expectations for the protection of personnel from the hazards inherent in handling radioactive materials. The policy states that "every effort is made to prevent personnel exposure from exceeding the Radiation Protection Guideline established by the Federal Radiation Council, the provisions of the AEC Manual Chapters" (subsequently ERDA and DOE), "or those established by the National Committee on Radiation Protection and Measurements; the maintenance of radiation doses as far below these standards as is practical is also encouraged."

The most significant safety and health programs implemented at the PGDP from the commencement of Plant operations until 1990 are summarized below.

Hazard Identification and Analysis, and Safety Training Programs

Several hazard identification and control activities that were initiated in the 1950s, such as safety procedures and safety committees, continued throughout the Plant's history. The Paducah Plant Safety Department, for example, was issuing safety procedures, standards, bulletins, and manuals as early as mid-1953. These early publications focused on a variety of physical hazards and issues such as housekeeping, fall protection, floor markings, signs on safety showers, vehicle accidents and fire protection. Safety Bulletin No. 4, for example, which was published in June 1953, provided instructions for testing scaffold planks.

The JHA process, which formally evolved in the early 1960s, became the dominant hazard identification process at Paducah and has retained its importance to the present. A precursor to the JHA process was a handbook developed by the Plant Safety Committee in 1959 entitled "Your Guide to Working Safely," which included a chapter on "Safe Practices and Job Methods." During the fourth quarter of 1965, a significant effort to revise the existing JHAs and prepare new JHAs was recorded in a quarterly Plant report. New employees in the late 1970s reported that their first work activity was to read several three-inch binders of JHAs to familiarize them with their work activities, the associated hazards, and the required controls. Industrial hygiene-related procedures on chemicals and respiratory protection, however, did not evolve until the 1980s.

Safety meetings also evolved in mid-1953 and have continued to the present to provide a mechanism for hazard identification, with an emphasis on worker involvement. For example, a safety bulletin was issued during the first quarter of May 1953 entitled "Suggestions for the Preparation and Conduct of Safety Meetings." In 1956, training conducted during safety meetings focused on "Toxic Effects of TCE." In 1957, workers were informed of the hazards of heat stress. One training vehicle that was popular in the 1950s and 1960s was the use or production of safety movies. One Paducah-generated movie on vehicle safety, entitled "Dancing Dolls," was submitted to the National Safety Council in 1958 for award consideration. During an Operations Department Safety Meeting in 1957, a program was initiated to display a large yellow flag each month in the area of the Plant that had the highest injury rate. In 1958, refresher training was provided to supervisors in "techniques for conducting more effective safety meetings." By 1971, safety meetings had become more formal, and all supervisors were required to attend. During the fourth quarter of 1972, a Four-Plant Industrial Hygiene Committee was appointed, with the initial meeting held at Y-12 on October 11, 1972.

Hazard Communication Program

From the outset, radiation and chemical hazards associated with PGDP activities and operations were known; this information was communicated to employees with varying effectiveness. Delays in initial Plant startup gave the workforce the opportunity for relatively extensive hazards training, as evidenced by classroom lecture material presented by the Health Physics Department to all operator and maintenance trainees during 1951 to 1953. During this period other Plant employees, including fire, guard, janitorial, warehouse, and property clerk personnel, received similar instruction, albeit in a condensed format. Paducah community emergency squad personnel also were provided training.

While the aforementioned delays in initiating operations in the early 1950s may have given supervisors more opportunity to ensure that hazards were effectively communicated to workers (relative to subsequent years), there is evidence suggesting that the early programs may not have been comprehensive or highly effective. For example, a review of grievances filed by union workers during the 1950s provides evidence that not all workers had a clear understanding of the need to wear anti-contamination clothing. Contributing to this situation was the discretionary application of Carbide's policy on anti-contamination clothing and a non-conservative approach to the provision of company clothes. Once Plant operations were under way, Carbide management sought ways to acquaint newly acquired personnel with known hazards without impacting production. An April 1958 letter from Carbide management advised all Plant supervisors that "radiation presents a hazard and…must be considered with the same degree of importance as any other hazardous condition." The letter continues by stating that "it is necessary to know the precautionary measures…to reduce the hazards [so that] no unsafe condition will exist."

Efforts to streamline and condense the classroom lectures of earlier years included a series of four one-hour lecture sessions presented by the Paducah Plant Physics Committee to PGDP employees in June and July 1958. The subject material included radiation theory, sources of radiation and methods of detection, non-penetrating radiation, and penetrating radiation. This lecture material was subsequently formalized in the 1959 *Health Physics Training Manual* and was used later to make a movie entitled *Uranium and Us,* which was shown to all PGDP employees for orientation in lieu of extensive classroom training.

The orientation training provided to workers in the late 1950s and 1960s addressed basic atomic theory, protection of personnel from radiation, and critical reaction. Once on the job, the worker was responsible for following more detailed instructions, such as those contained in the *Operator Training Manual* and specific *Standard Practice Procedures* (SPPs). Basic radioactive material control SPPs were identified in the Paducah Plant health physics program. Mentoring (that is, on-the-job training from experienced workers and supervisors), safety meetings, suggestion programs, and emergency squad training supplemented worker orientation training.

The communication of Plant hazard information to the initial operating workforce in the early to mid-1950s and PGDP workers in subsequent years was not always rigorous or consistent. For example, operations and maintenance personnel during the early 1950s received approximately ten hours of formal health physics training, followed by a written examination. This training was tailored to individuals by job classification (for example, maintenance, operations, and instrumentation and electrical) and by Plant location (for example, the feed plant). By the mid-1950s, after initial Plant startup, comprehensive safety meetings conducted by the Health Physics and Hygiene Department began to supplant the formal classroom training of the early years, although the meeting agenda was similar, addressing radiation, chemical, and other Plant hazards.

Throughout the 1960s, there is evidence that classroom training continued to be provided to employees, albeit still tailored to specific job activities. The level of rigor, however, appears to have declined substantially, since fewer than half as many hours were devoted to hazard communication as in the early 1950s. By the end of the 1960s, there is evidence that Carbide managers were addressing retraining of the workforce to review Plant hazards.

Increased production in response to demand, and the corresponding expansion of the workforce from 1,700 in 1954 to 2,500 by 1978, decreased the time and resources available for training. Accordingly, on-the-job training began to emerge as a principal means by which workers were advised and kept apprised of Plant hazards. Review of formal programs to communicate hazards in the 1970s suggests further degradation in the level of attention to this subject. For example, a ten-week program scheduled to begin on April 7, 1970, to "acquaint technical and supervisory employees with the…Paducah Plant" devoted only 2 1/2 hours to health physics, safety, job hazard analysis, and accident prevention. Additional evidence suggests that this trend may have continued, because even fewer hours were spent on communicating Plant hazards in a 1972 supervisory training and orientation program.

Documentation and records attesting to hazard communication activities at PGDP during the 1980s were not discovered during this investigation. Recollections of past and current employees indicate that some orientation was provided. However, there does not appear to be anything presented to employees that resembles the intensive classroom training of earlier years, as on-the-job training continued to emerge as the principal mechanism for communicating Plant hazards to workers.

There is sufficient evidence that formally prepared written material on Plant hazards has existed. For example, the Paducah Plant health physics program, the *Health Physics Training Manual*, and a variety of SPPs reflect Plant hazards in terms of the precautions workers must exercise to protect themselves. There is no evidence of the extent to which this information was either made available or required reading, nor is there any indication of supervisors' diligence in ensuring that Plant health and safety hazards were being communicated to workers.

External Exposure Monitoring Programs

External radiation exposures at PGDP from the 1950s to 1990 were monitored by both the Health Physics and Hygiene Department and line management. The Health Physics and Hygiene Department was responsible for performing beta-gamma radiation monitoring of the general work areas, equipment surfaces, material shipments, and personnel on a routine and spot basis and reporting findings to appropriate supervision with any necessary recommendations. The responsibility for performing routine radiation detection surveys lay with the line division concerned with the work being performed. Each division was responsible for identifying equipment having significant radiation exposure potential and establishing work time limits.

Personnel exposures were primarily monitored by the use of film badges. Health Physics and Hygiene program documentation indicates that after July 1, 1960, film badges were assigned to all employees, and were supplied to all individuals who visited the Plant from other locations and who might have been exposed to as much as one-tenth the RPG. Before July 1960, only selected workers were included in the film badge service based on their work activities. For example, in 1956 and 1958, there were 350 and 450 employees in the film badge service, respectively. Before 1960, the basic film badge use period appeared to be one week; in the early 1960s, the period was extended to one calendar quarter. However, for employees whose work involved significant exposure and who might have exceeded the quarterly RPG, badges were read and exchanged monthly. Review of documentation indicated that the employees on the monthly exchange cycle were primarily involved in chemical processing, maintenance of chemical processing facilities, and uranium metal production.

Review of documentation indicated that in general, the low specific activity and the self-shielding properties of uranium limited dose rates at PGDP. However, as stated in Health Physics quarterly reports, certain operations were known to result in "concentrations of material having higher specific activity and having created conditions that, if undetected, could result in exposures above permissible limits." Routine whole-body beta exposures over PGDP investigation levels existed primarily at areas where uranium daughter products and transuranics tended to concentrate, including the feed plant fluorination towers, converter disassembly areas in C-400 and C-720, the cylinder wash facility in C-400, the C-340 metals plant, and the neptunium and uranium recovery process raffinates. Interviews with Health Physics and Hygiene Department staff also indicated that exposures to external radiation were managed to assure that no one went above their lifetime limit (5N-18 rem, where N is a worker's age in years). It was common to rotate workers through areas of high external exposure concern, such as the ash receiver area, to administratively control individual exposures.

Interviews and documents indicated that in the early 1950s a decision was made that extremity monitoring was not required because it was felt that these doses were not likely to exceed 2.5 times the whole-body exposure. Whole-body exposures to operators and the dose rates in the ash receiver area were large enough that they could exceed 10 percent of the extremity limit and, therefore, would necessitate extremity monitoring. Shell and crucible cleaning operations in the metals plant required time-consuming wire brushing. In this activity, an individual would reach into a mold containing oxides rich in uranium daughter products (primarily beta emitters) and physically clean off the materials from the walls and bottom. The individual's film badge, worn on the torso, would typically be shielded from the majority of the beta activity by the crucible itself. However, since the whole body exposures to operators and the dose rates from these shells and crucibles are large enough that they could exceed 10 percent of the extremity limit, this practice would also have necessitated extremity monitoring. However, Health Physics and Hygiene Department summary reports provided no extremity monitoring data. Two documented, known beta overexposures (skin of the whole body quarterly limit) occurred at the C-400 cylinder wash facility during the first quarter of 1968. However, the investigation of this event was inadequate and did not address or determine extremity dose.

Bioassay – Urinalysis Programs

Individual employees were required to submit urine specimens for uranium analysis at a frequency thought to be commensurate with exposure potential, as well as for periodic physicals. Additionally, special urinalyses were scheduled for those working on special jobs, or when some special investigative information was required. The frequency of routine urine samples for uranium varied from a maximum frequency of four weeks for all personnel working in chemical operations and metal production (primarily C-310, C-315, C-340, C-400 and C-410) to a minimum frequency of 12 months for those working in locations deemed to have little likelihood of exposure. The Health Physics and Hygiene Department routinely issued a master schedule to line management showing when specific samples should be taken from certain groups of employees. This schedule typically covered three calendar months. Action points for uranium levels in urine were established, setting forth recall-sample frequencies, supervisor notification, and investigation reports. These action points ranged in levels from just above detection capability to greater than RPGs. The actions that were taken were commensurate with the result, typically ranging from requiring recall samples, workplace investigation, workplace restriction, estimate of body burden, and internal dose and/or confirmatory in vivo radiation monitoring (e.g., lung counting).

Interviewees employed during the 1952 to 1990 timeframe recalled numerous instances of being administratively removed from work because their samples came up “hot.” These individuals received no further explanation that they could recall. However, the requirement to submit additional samples until they were no longer “hot” is consistent with the recall sampling and exposure determination program. Interviews with both former production workers and Health Physics and Hygiene Department staff members indicated the reliance on supervisors to notify workers for recall, and the movement of some workers throughout the Plant made bioassay timing sometimes difficult. In addition to routine sample submission, the Health Physics and Hygiene Department attempted to obtain samples from any individuals involved in releases for sample collection, but records indicated that they were not always successful.

Employees who were administratively removed from work because of exposures were reassigned to areas with less potential for intake, although typically still in areas where uranium work was conducted. The urinary uranium excretion rates were followed for these individuals until the urinalysis results were understood from a solubility standpoint or until rates decreased to baseline values; the personnel then returned to their regular work activity. Biological retention times for these types of exposures are closely related to the solubility class of the compound. Although the health physics group actively tried to gain insight into solubility class and particle size, much of this information was not well understood during the early 1950s and 1960s.

Interviews and much of the sample analysis data revealed that intakes were assumed to be from soluble compounds. This assumption may not have been true for some aerosols generated in the feed plant and during operations where metalworking (e.g., grinding, buffing, and welding) may have resulted in a range of particle sizes of insoluble material. The solubility information would have been important in determining the appropriate routine sample collection frequencies and for computing dose based on uranium concentration in urine. The Health Physics and Hygiene Department maintained in a response to a 1969 AEC-sponsored study on particle size determination that “While we have done very little particle sizing work over the years, we feel that our air-sampling technique and our bioassay program in combination have provided our employees with excellent health protection at relatively low cost to the AEC and the tax payers.”

The documents reviewed indicated that urine samples were also collected and analyzed for transuranics, including neptunium and plutonium, and fission products such as technetium. These samples were typically collected following work on systems thought to have built up a concentration of these materials or associated with recovery of these materials. Samples were typically transferred to Oak Ridge for analysis. Interviews referenced some limited onsite laboratory capability for analyzing neptunium samples and fecal samples for plutonium. Review of Health Physics and Hygiene monthly reports for the early 1960s indicated that urinary excretion rates for neptunium had been steadily increasing.

Feed Plant

While the Health Physics and Hygiene Department correspondence indicated historical difficulty in relating results from air samplers to bioassay data, PGDP attempted to gain additional knowledge pertaining to this relationship. A review of the Health Physics Steering Committee files indicated that during meetings in March and May 1958, the Alpha Subcommittee proposed exposing volunteers to known concentrations in air of UO_3, UO_2F_2, and UF_4 to gain an understanding of excretion rates and urinalysis compared to air sample results. Interviews conducted with Health Physics and Hygiene staff employed during this timeframe confirmed that an intentional intake of a known quantity of UO_2F_2 in air was conducted by volunteer health physics staff members. Their excretion of urinary uranium was then tracked and compared to known air sampling data. The results of this experiment could not be found. In another attempt to gain insight into the relationship between ingestion and excretion, a senior health physics staff member drank a known quantity of a uranium-bearing solution in order to understand the excreted fraction. This data was never published.

In 1957, the Health Protection Study Committee at OR issued a report entitled "Health Protection at Paducah and Portsmouth." The committee's summary noted that "It seemed to the committee that undue emphasis is being placed at Paducah on the technique of bio-assay for evaluating exposures to uranium." The report goes on to compare and contrast practices at the two plants and makes recommendations for continuous improvement. Given the size of the air sampling and bioassay programs at Paducah and the relatively few health physics staff, it appears that this greater reliance on the urinalysis program continued from the 1950s through 1990.

Bioassay - In Vivo Radiation Monitoring

In vivo radiation monitoring via lung counting for PGDP workers was conducted initially at fixed facilities at Fernald and Y-12 in Oak Ridge and later at PGDP using a mobile system from Oak Ridge. Data indicated monitoring for uranium, neptunium, and technetium, and generally indicated no significant accumulation of radioactive material in the lungs in excess of RPGs. However, a review of the PGDP quarterly report for July-September 30, 1966, Health Physics and Hygiene summary, indicated that a PGDP maintenance mechanic who had been excreting an elevated level of uranium (approximately 50 micrograms per day) since March was checked in the Y-12 in vivo radiation monitor, and his lung burden was below the detection level in effect at this time. *Radiation Protection Criteria and Standards, Their Basis and Uses at AEC Facilities Operated by Union Carbide Corporation* stated that "an excretion rate of approximately 50 micrograms per day may be considered indicative of a significant internal body deposition of normal uranium." This discrepancy calls into question the accuracy and detection sensitivity related to early in vivo radiation monitoring conducted at, or for, PGDP.

In vivo monitoring was often conducted following discovery of elevated levels of material in air or urine samples. An example of this practice resulted from air samples collected during the first quarter of 1979 for the C-400 converter bundle salvage operations. In vivo results indicated that several personnel had elevated lung deposits of uranium. The Health Physics and Hygiene Department concluded that "When urinalysis, air samples and in vivo was considered jointly the assumption is that concentration was due to insoluble uranium and soluble neptunium." Plutonium was detected in some air samples in significant concentrations during this operation, according to the survey document.

PGDP documents addressing neptunium measurements made during the 1960s state that "good sensitivity was obtainable" for the Y-12 system, although the data indicated that no detectable deposits of neptunium were found in employees who were monitored by this system. Subsequent measurements were made between 1968 and 1974 using the mobile IVRML at the PGDP. However, the investigation team believes that the accuracy of these results is questionable because the IVRML was not routinely calibrated for neptunium, nor were neptunium results recorded. During the mid-1970s and 1980s, measurements were also made for neptunium. Records from this period indicated that any retention of uranium or transuranics was determined by PGDP to be well below the Maximum Permissible Lung Burden.

Air Sampling

From 1952 to 1990, the PGDP used a network of stationary air samplers at various production and non-production areas throughout the Plant. Portable and breathing zone samplers supplemented this network. Much of the data indicated frequent air sampling results in excess of PGDP RCG levels. Review of Health Physics and Hygiene monthly summary reports between 1955 and 1968 indicated that it was common to have air samples collected by both stationary and portable air samplers that exceeded MAC values. These excursions typically were related to a process upset, equipment failure, or maintenance activity. Logs reviewed indicated many dusty operations or smoky conditions related to activities; however, many health physics reviews noted no apparent determination of the cause(s) of these conditions. Interviews with Health Physics and Hygiene Department staff members employed during this timeframe indicated that stationary air samplers monitored the processes throughout the PGDP to indicate problem areas, but they were not used to attribute dose to individuals.

Several air samples that were collected during the first quarter of 1962 in conjunction with converter disassembly work or maintenance were analyzed for the presence of neptunium. The total alpha activity from neptunium in sample results ranged from non-detectable to greater than 90 percent. A review of these evolutions also showed examples of airborne contamination ranging from non-detectable to more than 100 times the PGDP MPC for neptunium. Health Physics and Hygiene Department summaries throughout the 1960s referenced neptunium contamination of cascade equipment as continuing to present a difficult exposure control problem. Health Physics and Hygiene Department surveys of CUP work in the C-720-C Converter Shop in 1980 indicated that Plant guides for airborne alpha activity were exceeded for uranium by a factor of 1,680, neptunium-237 by a factor of 2,121, plutonium-239 by a factor of 2,483, and thorium-230 by a factor of 55. Assuming the PGDP stated factor for respiratory protection afforded by a respirator ("conservatively is 90% effective"), levels even one-tenth as great would be deemed significant. The specific operations identified as generating these high airborne concentrations—the use of an oxyacetylene torch to cut through jack screws from inside the converter and use of compressed air blow-through testing—were both subsequently abandoned.

In summary, there is ample evidence that airborne radioactive contamination and worker exposures were not kept as low as reasonably achievable (ALARA) from startup into the 1980s. Workers received much greater exposures than if the stated AEC/PGDP ALARA policy had been fully implemented and actions had been taken to prevent and quickly moderate high airborne activity in work areas.

Contamination Control

A review of Plant health physics records indicates that many radiation and contamination surveys were conducted as far back as the 1950s. While health physics personnel generally were aware that contamination control practices were desirable, these practices were neither rigorously enforced nor mandatory. Radioactive contamination in the workplace was considered ancillary to the process operations and was considered to be of significant concern only if it gave rise to high dose rates or contributed (by way of resuspension) to high airborne concentrations of radioactive material that could be inhaled. In June 1955, a health physics memo noted that contamination levels in C-410 were higher than at any previous time. It stated that excessive amounts of powder were present and the settling of UF_4 on the west mezzanine floor amounted to a green film that was noticeable even after the floor had been swept. Similar conditions and findings were noted in various health physics inspection reports and surveys through the 1960s and 1970s as well as numerous prior worker accounts of the work environment. The recurring nature of these findings from health physics inspections indicates that corrective actions were not taken to minimize these conditions or were ineffective.

C-100 Administration Building

Several other memos and reports in the 1950s and early 1960s dealt with the notion that ingestion of uranium compounds might not be particularly harmful, based in part on the findings from animal studies conducted at the University of Rochester. While not confirmed, it is possible that this may have been the origin of the often repeated comments during interviews that workers had been told the material they worked with was safe enough to eat. The animal study information was used in part to justify the concept that anti-contamination clothing (coveralls) was not needed for all personnel. The Health Physics and Hygiene Department concluded that the main mode of exposure from contamination on the clothing would be ingestion rather than resuspension/inhalation, and the hazard would be essentially nonexistent for low levels of contamination on personal clothing. The criteria for issuance of company clothing resulted in numerous union safety grievances throughout the 1950 to 1980 time period. There appears to have been no concerted effort by management to ensure that lunchrooms were free of radioactive contamination, and as recently as the late 1980s, many workers were allowed to smoke and eat lunch at their contaminated work locations. While designated lunchrooms were likely to be cleaner than process areas, up until the late 1980s to early 1990s, there were no contamination control zones that would have minimized or eliminated the spread of contamination to these areas.

Contamination control practices were lax at Paducah from the beginning of operations until the mid-1980s, when more stringent contamination control and radiological release criteria were promulgated by both NRC and DOE. This is evidenced not only by the aforementioned health physics inspection reports and worker accounts but also by the legacy of posted contamination areas that remain within the various Plant buildings and grounds. In the late 1980s, the Health Physics and Hygiene Department undertook an effort to survey some Plant locations considered to be non-radiological areas. Findings included contamination in a variety of locations, including the C-100 "Roxie theatre," where personnel would gather for briefings and meetings, as well as various "non-radiological" lunchrooms throughout the site. In one survey evolution, 83 percent of the 150 anchored seats in the Roxie theatre were found to be contaminated, and 47 percent of the lunchrooms surveyed were found to have contamination above the limits for non-radiological areas.

While most labor personnel who were issued company clothes showered and changed clothing before leaving the site, the effect of the lax contamination control practices of prior decades makes clear the probability that radiological contamination was not confined to the work spaces, but was likely taken outside the site boundaries by workers wearing personal clothes on the job. No records of formal radiological monitoring for personnel and equipment leaving the site were noted until the 1986 timeframe.

Personal Protective Equipment

The use of PPE, and particularly respiratory protection equipment and coveralls, was inconsistent at PGDP. As early as 1952, the Health Physics and Hygiene Department recognized the potential hazards associated with personnel contamination and instituted measures to attempt to control potential exposures, including regular work area radiological surveys to determine the levels of personnel and clothing contamination. These surveys clearly indicated significant levels of radiological contaminants on hands, clothing, and shoes.

In several Plant areas, frisking devices were installed to allow personnel to self-monitor for radiological contaminants after hand washing before lunch and at the end of shift. Several thousand survey records for the period 1952 to 1956 indicate that significantly less than 1 percent of the personnel performing self-monitoring activities identified contamination on their hands. No routine survey program was established for clothing or shoes. These survey data are inconsistent with the results of numerous Health Physics and Hygiene lunchtime surveys of personnel and clothing that identified personnel with enough hand and clothing contamination to make ingestion of radioactive material a concern. Nonetheless, on January 1, 1957, the Health Physics and Hygiene Department issued a letter to all division superintendents stating that workers did not need to wash their hands before eating to avoid concerns with radioactive contamination. Shortly after this letter, the use of hand counters was discontinued at the Plant until the 1980s.

In January 1957, the Health Physics and Hygiene Department issued a memorandum to Paducah management entitled "Hand Contamination," which evaluated entry pathways for uranium into the body. The conclusions presented in the memorandum were based upon studies at AEC and research facilities. For inhalation of uranium, the memo concluded that "smoking with contaminated hands is not a significant factor in uranium exposure." For ingestion, the memo stated that “Animal feeding experiments showed that insoluble compounds of uranium may be ingested in relatively large amounts without hazard.” Similar conclusions were associated with injection of uranium into the skin of the hand. In 1958, Health Physics and Hygiene management recognized that major portions of the beta radiation exposure to workers resulted from contaminated coveralls. The Health Physics staff estimated exposures and added that to personnel exposure records. Typical annual additional skin doses due to contaminated coveralls were recorded in the 500 to 800 mrad range.

There is evidence of some management effort to minimize the use of protective clothing at the site, and the Health Physics and Hygiene Department was actively involved with contamination control issues associated with the use of personal clothing in process areas. Following a 1956 review of the C-720 Electrical Shop, Health Physics and Hygiene stated that “Nothing was found which could be considered as detrimental to the health of the men working in this shop or to their families as a result of contamination being carried home on shoes or other clothing.” In July 1957, management directed that personal clothing would be used on all work in the C-720 Control Valve Shop. However, evidence suggests that Paducah personnel routinely exceeded personal clothing contamination limits without corrective actions being taken by management. Health Physics surveys in the C-720 Control Valve Shop measured personal clothing contamination levels up to 2.5 mrad/hour and 1,250 dpm alpha. Similar measurements were identified in October 1957, with the stipulation that the use of personal clothing was approved as long as beta doses did not exceed 600 mrad/week. This threshold was quite high, considering that an exposure of 600 mrad per week in a year’s time would exceed the maximum allowable annual beta skin exposure of 30 rem. In neither case was consideration given to the possible contamination and exposure to non–Plant workers associated with home laundering of the clothing.

In 1967, Health Physics and Hygiene management presented a position paper to all Paducah Plant supervisors, discussing use of contamination clothing. Although the paper acknowledged applications where PPE should be utilized to maximize skin protection, the paper concluded that contamination clothing issuance was not based on past practice, but on whether or not clothing contamination levels of 4,000 cpm alpha were expected during the work to be performed. If contamination levels were not expected to exceed 4,000 cpm alpha, personal clothing was to be utilized. The paper also highlighted supervision’s responsibility to determine when contamination clothing should be issued and offered the Health Physics and Hygiene Department’s support in conducting surveys and providing supervisors with facts and advice. Interviews during the investigation indicated that supervisors and foremen were never issued company-type clothing, even though in many cases those personnel were exposed to the same radiological hazards as the workers.

Respiratory Protection

The site’s Health Physics and Hygiene Department considered personnel exposures to low-enriched uranium compounds to constitute a chemical rather than radiological exposure. Not only were the constituents of uranium compounds within the enrichment cycle hazardous (e.g., fluoride and acid compounds), but heavy metal poisoning could result from exposures to significant quantities of low-enriched uranium. Consequently, respiratory protection programs of the time were instituted to minimize personnel exposures to these contaminants. In general, the respiratory protection program utilized two basic types of respiratory protection equipment, the MSA Dustfoe and the Army assault mask, to minimize personnel exposures to dust-type and chemical contaminants, respectively.

As early as 1953, Paducah management was aware that feed made from recycled reactor fuel processed through the enrichment cascade contained trace quantities of plutonium. Evidence indicates recognition of the potential for personnel exposures to these contaminants. However, at least initially the respiratory protection program and health physics surveys and monitoring did not fully consider the presence of those contaminants. It was not until 1957 that the Health Physics and Hygiene Department discovered, during surveys, that neptunium-237 had also entered the process stream from the reactor return feed materials.

During this period, the Health Physics and Hygiene Department, as well as designated Operations personnel, routinely collected air samples throughout the site. Sample records indicated that airborne contaminants, noted as alpha contaminants, exceeded the MAC. In many cases, after the fact, Health Physics and Hygiene personnel routinely recommended the use of respiratory protection devices for specific tasks with identified high airborne radioactive material concentrations. However, the evidence suggests that although line management acknowledged receipt of those recommendations, they were not always implemented.

In September 1953, urine bioassays for personnel involved in ash receiver handling operations identified two workers with positive results for plutonium, suggesting that personnel did not routinely use respiratory protection equipment during these activities. As a result of this determination, the site's Health Physics and Hygiene Department recommended suspending the practice of transferring ash receivers to drums as a means to reduce potential airborne plutonium levels.

In 1957, radiochemical analysis of impurities from wet chemistry processes at the site revealed the presence of both plutonium and neptunium. Further study concluded that the contaminant was confined to the chemical processing areas of the Plant. However, during Health Physics surveys in the Weld Shop in 1957, unusually high alpha contamination levels were detected on large diameter process piping. Records indicate that no visible uranium was present on the work piece, even though high smearable alpha contamination was detected. Radiochemical analysis of swipe samples indicated that 50 percent or more of the alpha activity on the work piece was due to neptunium-237. This finding resulted in recognition that the entire cascade was contaminated with neptunium, and studies were conducted to determine which jobs presented the highest potential for exposure.

Many jobs were assessed for potential neptunium exposures; Health Physics and Hygiene concluded that the disassembly of converters presented the highest exposure potential. Although the record indicates that dust respirators were used during converter work, elevated air sample results clearly indicated that airborne neptunium contamination presented a serious personnel exposure problem. Additional control measures were evaluated and implemented, including the use of ventilation systems and wetting of surfaces to reduce dust dispersion. When equipment size or configuration precluded the use of other control measures, records indicate that the use of air-supplied hoods was recommended.

It is clear that the Health Physics and Hygiene Department actively promoted the use of respiratory protection devices in areas with high potential for airborne and/or chemical contaminants. Records indicate that the Health Physics and Hygiene Department routinely interacted with operations management and workers to advise on the use of respiratory protection equipment and provide counsel on the types of work that would normally require respiratory protection. However, archived records indicate that despite the Health Physics and Hygiene Department's concern with personnel protection, that group did not have the authority to direct the use of respiratory protection. Consequently, records also indicate that respiratory protection was not always utilized when high levels of airborne contaminants were present. For example, a Health Physics and Hygiene Department quarterly report for the first quarter of 1959 reported that continuous air samples collected near the neptunium recovery operation in C-710 averaged slightly above the MAC assumed for neptunium. Later analysis indicated that 29 percent of the alpha activity was attributable to neptunium. There is no indication that respiratory protection was used during these activities. Urine samples collected and sent to ORNL for analysis tested positive for neptunium.

It was also noted that work was routinely conducted without the benefit of respirators on open cascade components in process buildings, maintenance and refurbishment work, and waste handling activities, which were known to contain transuranic compounds. Records and interviews also indicated that respiratory protection was not always used during UF_6 releases in process areas, and it was common for operators or Operations supervisors to enter the area of an active UF_6 release without respiratory protection or other PPE in order to stop the release.

It is unclear why the discrepancy between Health Physics and Hygiene initiatives and actual work practices existed, although the Twenty-first Semiannual Report of the AEC, January 1957, page 176, may shed light on this inconsistency. The AEC, in noting that certain patterns of administration were common among the contractors, stated in part that "The role of the health physicists, where actual enforcement of radiation safety on the job is concerned, is cautionary and advisory. The supervisor in charge of a certain piece or area of work is the man who is answerable to management for the workers' protection, and for safe operations in general."

The Health Physics and Hygiene report for January 1962 outlines that urinary excretion rates had steadily increased over the past several years, to the point that some personnel were now excreting as much as 3 dpm/24 hour specimen. By today's standards, the dose represented by this excretion rate would be well in excess of regulatory limits (i.e., the team calculated a Np-237 excretion rate of 2 dpm = 2,000 rem to the bone). This report also notes that the time-weighted average airborne neptunium alpha activity in the breathing zone of personnel disassembling converters from C-337 had increased and was 237 dpm/m^3, with 90 percent of the alpha activity in the deposited dust on the equipment coming from neptunium. Controls included additional vacuuming and the use of air-supplied hoods instead of dust masks.

There is evidence that as late as 1973, inconsistencies in the use of respiratory protective equipment remained. The site attempted to justify these inconsistencies by noting that the guidance to employees allowed workers to choose whether to use a respirator, and what type, based on their perception of odor or visible fumes in the work area. It is evident that respirator use during this period remained largely voluntary, since the guidance only recommended that personnel leave the area of air contamination when necessary to obtain proper respiratory protection for the contaminant encountered. It is interesting to note that in 1973, uranium compounds were the only radiological hazard mentioned in the respiratory protection guidance, even though during the years 1969, 1970, 1972, and 1973, the highest percentage of reactor tails (with their attendant transuranics) were fed to the cascade.

At least two respiratory protection experiments were conducted at Paducah involving Plant personnel; the record is unclear as to whether the personnel involved in the experiments were volunteers or informed that they were participants. A March 1, 1956, memorandum, "Field Tests of Respirator Efficiency," documented the results of experiments at Paducah, involving the exposure of eight subjects to UO_2F_2 fumes to test the filter efficiencies of various respiratory protection systems. In this experiment, two subjects wore a combination dust and acid gas respirator and were exposed for one hour to UO_2F_2 fumes generated by hydrolysis of UF_6 in the dismantling booth in C-400. Three additional subjects wore the MSA "All Dust" respirator and were exposed to UO_2F_2 smoke for one-half hour. An additional three subjects wore the assault mask and were exposed to higher concentrations of UO_2F_2, sufficient to limit visibility to 10 to15 feet. All eight test subjects submitted urine samples, which were subsequently analyzed to determine respirator efficiencies. This memorandum also appears to indicate that these were not the first experiments undertaken at Paducah, although records of previous tests were not discovered during this investigation.

A November 1, 1956, memorandum entitled "Test of Dustfoe 66 Respirator" documented the results of an experiment at Paducah. This involved the exposure of six subjects, previously known to have insignificant uranium excretion, to a typical UO_2F_2 release while wearing Dustfoe 66 respirators. This experiment was conducted to determine the efficiency of the respirator filter and involved a measurement of the total uranium excreted by each test subject for the 24 hours after the test. References cited in the experiments noted above indicate that a variety of other urinary uranium excretion experiments were conducted on human subjects at a variety of facilities, some within the Oak Ridge complex.

Respiratory protection issues have continued throughout the Plant's history, as evidenced by concerns raised in DOE's technical safety appraisal of the Plant in April 1987. This report noted that implementation of the radiation protection and contamination control programs was designated as a line management function with the support of the Health Physics and Hygiene Department. The report went on to state that "Line management is not qualified either by virtue of training or expertise to specify radiation protection and contamination control requirements" and that "They [line management] recognize they are responsible but appear to regard radiation protection as not being a significant safety concern." Other sections of the report noted inconsistencies in industrial hygiene program implementation, including the absence of baseline surveys, monitoring, and respirator control and maintenance.

Medical Programs

A formal medical program to monitor and treat workers has been in place since the initial construction phase of the Paducah Plant. Union Carbide Corporation, AEC, ERDA, and ultimately DOE have had documents in place that reflected the basic concepts of occupational medicine during their periods of authority. Provisions have always been in place for medical personnel to respond to emergencies, conduct examinations, treat illnesses and injuries, and monitor both work-related and personal health issues. Until the 1980s, the Plant Medical Director had management responsibility for the medical, industrial hygiene, and health physics programs at the Plant. This management relationship greatly contributed to the physician's knowledge of workplace hazards, workplace concerns, and health effects at the work site.

Mandatory and voluntary examination programs were provided to all employees working at the Plant. Pre-employment examinations, termination examinations, and examinations for some job classifications were conducted on a regular, non-voluntary basis. Other employees were offered voluntary examinations depending on age or special needs. Examinations were comprehensive and included standard components such as history and physical, hearing test, laboratory studies (blood and urine), chest x-ray, cardiogram, and eye examination. Later on, more sophisticated studies, such as pulmonary function, comprehensive blood chemistry studies, and glaucoma testing, were added to the protocols. Along with the promulgation of industrial standards and regulations, medical surveillance requirements for regulated substances (such as asbestos) and medical approval for persons working in potentially hazardous situations requiring respirator use were incorporated into the medical program.

Employee medical records have been retained locally for most former and current PGDP employees. Some exceptions include employees who may have been transferred to other Federal facilities or a few records that may have been misplaced or lost. The medical records contain the results of all physical examinations, personal and occupational treatments rendered by the medical staff, major medical insurance records, and all work-related incidents or accidents that required medical intervention. Of special interest are the incident/accident reports, especially from the 1950s and 1960s, that chronicle the nature and extent of worker exposures to process gas, HF acid, and welding injuries.

It was evident from interviews and the review of official PGDP publications, such as the AEC quarterly report, that medical personnel were aware of and concerned about the long-term effects of exposures to chemicals and radiation; however, physical examination results did not appear to discuss or target those concerns. Quarterly reports document that no major long-term health effects from these exposures have appeared in the Plant population. Similarly, very little exposure information was included in any individual medical record, but interviews with former medical personnel indicate that exposure information was available if needed by the physician.

Several former workers noted during interviews that in the 1950s and 1960s, some employees working in or near hazardous operations did not receive the required medical examinations. For example, machine shop employees working in C-720, adjacent to the compressor maintenance shop, reported that although they may have been routinely exposed to process gas and contaminated dust, they were not required to have protective equipment or participate in mandatory medical examination programs. This failure to recognize and monitor some obvious worker exposure groups was not explained by either the former workers themselves or documents available to the team.

Personal medical care for employees has always been important in the PGDP medical program. Many employees utilized the medical care available at the Plant to supplement the available resources in the community. It appeared that keeping workers healthy and productive at work was an important consideration for the medical staff, resulting in many personal visits to the dispensary for advice, medications, and treatment. It was also obvious from interviews that some employees considered routine exposures to gases and chemicals insignificant and simply part of their normal work routine. Therefore, they did not report minor skin irritations, congestion, nosebleeds, eye irritation, and other indicators of possible long-term health effects.

Identification of physical hazards received greater focus in the Plant's early history than did identification of hazards that resulted in an exposure. However, there were a few exceptions, such as noise, uranium, fluorides, and dust. Recording and trending of injury data, which began in the second quarter of 1953, continue today. Early recorded statistics included man-hours worked, number of minor and disabling physical injuries (e.g., cuts and burns), and man-days lost. The rates of both frequency and severity of injuries were calculated from the beginning of the Plant's history. (Illness statistics were not compiled until after the 1970s.) In the 1950s, the Health Physics and Hygiene Department quarterly reports typically identified 40 to 60 workers per quarter seeking medical attention as a result of accidental releases of uranium, hydrogen fluoride, and fluorine. In the second quarter of 1955, accidental releases of toxic material within the Plant were considered "minor" since "only 12 men reported to the dispensary for medical attention." The 1961 Paducah Operations Training Manual compared injury rates at Paducah to injury rates at common industrial sites (e.g., coal mining and lumber jacking). Although Paducah's disabling injury rate compared favorably, such was not the case for Paducah's injury severity rate.

3.2 Operations and Maintenance

Operations and maintenance activities are described below, as well as the effectiveness of controls to protect workers, the public, and the environment from hazards. In addition, Appendix B summarizes the principal hazardous activities conducted at PGDP during the period 1952 to 1990 and provides an assessment of the hazards presented by these activities, the controls used